Improving the usability and performance of heat recovery ventilation systems in practice

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ABSTRACT

The use of heat recovery ventilation systems is becoming more and more common. It is clear that these systems contribute to energy efficiency and good indoor air quality. Still there is room for improvement. Analyses by monitoring and modelling have uncovered drawbacks and flaws, especially for the use and application of HR ventilation in highly energy efficient dwellings. This paper will deal with these issues, turning them into suggestions to improve HR ventilation systems.

An important finding is the poor ability of HR ventilation systems to anticipate on increasing differences in room heating/cooling needs within a dwelling. The HR ventilation systems are not able to redistribute recuperated heat with differentiated ventilation, distinguished in time and per location. This invokes additional window use, not only resulting in a poor control of the indoor environment, but also highly reducing the overall energy gain of the HR ventilation system. This energy gain itself is often overestimated, due to insufficient insulation of the unit's outdoor ducting and blockage of the heat exchanger by condensation moisture. Furthermore, the high practical all year electricity use is not incorporated as well.

Another finding is the rigidity of HR ventilation as the anticipation on seasonal fluctuations is concerned. In fact the system is designed for non-freezing winter use, despite its summer bypass. Hence it operates most of the year in a non-optimal mode.

Several suggestions are done to improve the utilization of HR ventilation systems, such as zonal differentiation, incorporation of short term heat storage, moderations of the ventilation unit and improved control, as well as design recommendations for a low-noise moderate pressure ducting system.

KEYWORDS

Heat recovery, temperature differentiation, short-term heat storage

1 INTRODUCTION

The use of heat recovery ventilation (HRV) systems is becoming more and more common. It is clear that these systems contribute to energy efficiency and good indoor air quality.

In general, their application is in increasingly well-insulated dwellings. Due to the reduced convective heat losses in these dwellings, ventilation heat losses are more dominant and as a next energy saving step recuperation of them is obvious. However, it is not fully realised how this affects the dwellings heat balance. Hence, indoor climate conditions become less optimal, not to say sometimes even that poor that people will overrule the HRV system. The resulting discomfort may lead to less system adoption by users. Also, the energy saving effect of HRV will decrease and sometimes even becomes negative. This paper deals with this phenomenon and also reviews other ventilation and energy performance aspects as well as usability of HRV systems. Suggestions are done to improve HRV-systems on these aspects.

2 EFFECTS ON THE HEAT BALANCE

2.1 History of heating

In the early days houses were equipped with local fire places in occupied areas, only fired when people were present. They had a high degree of demand control. After the introduction of central heating systems people were able to heat up every room to a desired extend, just by controlling the local radiator valve.

Numerous measurements showed that desired indoor temperatures of living rooms were around 20°C and of bed rooms around 17°C. In poorly insulated dwellings this needed operation of the heating system below outdoor temperatures of about 19°C and 14°C for the respective room types. So, apart from very mild outdoor conditions there was an overlap in heat demand, though the level differed. Therefore, one could do with a climate system restricted to only heating mode.

Since heat losses were high and time constants were low (i.e. the product of building heat storage capacity and heat resistance), it was easy not only to differentiate in temperature between each room, but also to adapt the temperature level in a room quit fast. It meant that bed rooms cooled down to the restricted night temperature within a few hours after lowering the set point of the thermostat. Research of Hoes and Knoll [1] showed this was very convenient, since people initially need higher temperatures to fall asleep, but a decreasing room temperature after a while to prevent overheating (an uncomfortable sweaty bed).

2.2 Heating season temperature control of well-insulated dwellings

It is obvious that in modern, well-insulated dwellings the heat demand is lower than in non-insulated ones, apart from a more or less fixed addition for heating up. Less known is that heating system operation ends at lower outdoor temperatures and that the difference between the operation end points for living and bed rooms gets larger in the low energy building. This is shown in Figure 1 [*Note the outdoor temperature at probability scale*].

The 1975 dwelling in the graph represents the non-insulated building. This emerges to the 2020 dwelling at nearly zero energy level (NZE). The dotted lines are for the bed rooms. They show a clear distinction with the drawn lines of the living space, getting bigger at increasing energy efficiency. For instance, the 2005 dwelling [Rc = 3.5 m².K/W, glazing HR^+, n_{50} = 3.5 ach and 50% ventilation energy reduction] has a heating need in the living area during 85% of time, while in the sleeping area this is only 10%. In other words, while heating the living area most of time there is a cooling need in the bed area. Hence, modern low-energy dwellings should have a climate system that is able to simultaneously heat and cool in the different areas, preferably in an energy efficient way. However, this is far from common practice. Surplus heat is just rudely spilled by opening large windows during the heating season. This certainly is the case with central HRV systems. They impede the desired temperature differentiation by redistributing regained heat to rooms with cooling need. For this type of dwelling research by Jacobs [2] showed an energy impact of their window opening in the order of 7 GJ/a.

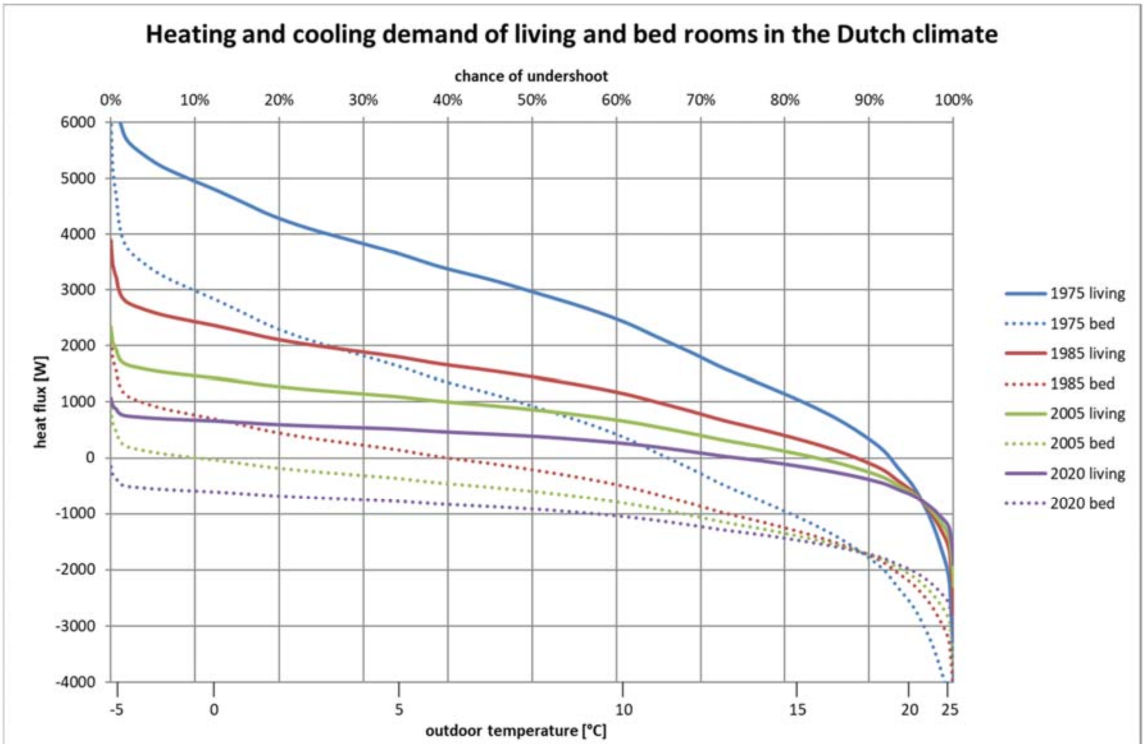

Figure 1 Heating and cooling demand of different rooms depending on insulation level

Another aspect is the 'short term' variation of the average dwelling heat demand. Often a dwelling of common insulation level is heated up at the start of day, needs to be cooled down again during daytime, to be heated again in the evening. Figure 2 is showing this (red colours is heating, blue colours is cooling; demand in W per dwelling).

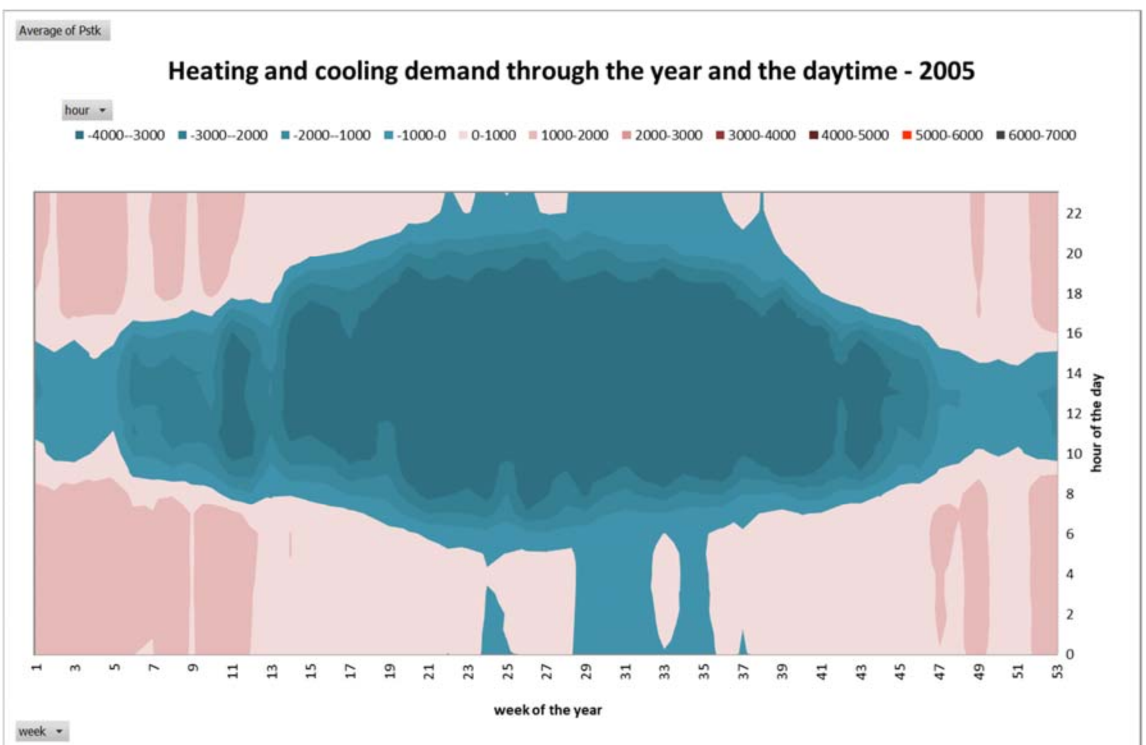

Figure 2 Energy-efficient dwellings often show both heating and cooling need within one natural day

The fast variation in heating and cooling over daytime is highly inefficient as energy is concerned. Efficiency would highly improve if one could extract the excess daytime heat, to temporarily store it and release it again in the evening or early morning, only in rooms with heat demand. Partly this damping of heat flux is already done passively by the building mass. However, both the dosage and dynamics do not fit. So inhabitants will intervene on this in a rude way. To prevent this, addition of an actively controlled short term storage is preferred. The suggestion is to use ventilation heat (recovery) exchangers to either withdraw excessive heat from the dwelling or to transfer stored heat to it. Since the heat or cold demand differs per room and in time, local heat exchangers are preferred, having a separate control per room. This improved HRV system distinguishes from the present system type by local ventilation heat exchangers, acting with an intermediate fluid and a central short term storage.

2.3 Passive cooling of well-insulated dwellings

Well-insulated dwellings do need proper means for passive cooling during summer time. In NZE dwellings the rate of the cooling need will even become competitive to the heating need. Combined with effective solar shading ventilative cooling has a good potential in the moderate Dutch climate. The flows should preferably be up to the order of 0.5 m^3/s, though 0.2 m^3/s will do to satisfactory limit the number of temperature overshoot (TO) hours. In any case, this range is well above the capacity of the HRV system. This means that a separate ventilative cooling system is necessary and that bypass control of the HRV system will only mitigate the temperature overshoot.
Analyses of HRV bypass control in practice had some remarkable findings.
At first, the most commonly used type is the partly bypass. This means the heat recovery will stay in function, but the larger part of the system flow (about 2/3) is bypassed around it. Hence, the system flow is not fully applied for passive cooling.
A more severe finding was the lack of control intelligence (see Figure 3).

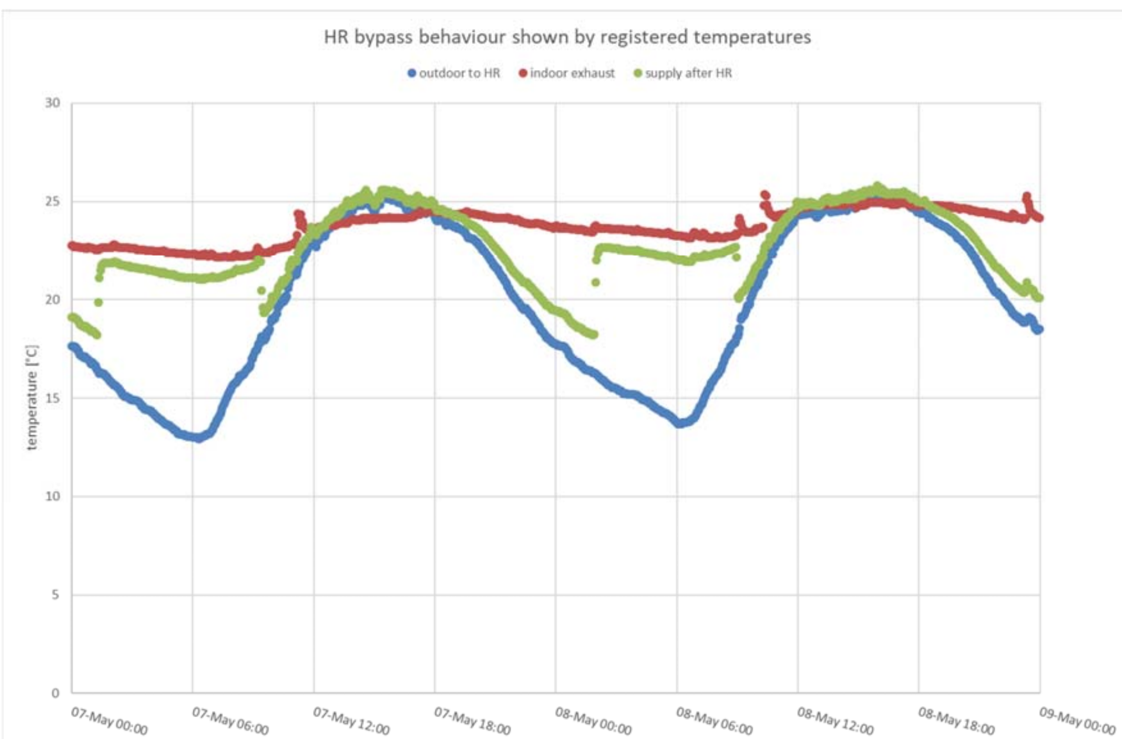

Figure 3 Illustration of bypass operation

In the illustrated case the bypass was allowed to operate if outdoor temperature was over 10°C. It opened when outdoor temperature got above a comfort set point (19°C) and outdoor was lower than indoor. It closed again when this was reversed, but taking into account a certain off set to prevent commuting. Due to this control behaviour during the warmest part of the day warm outdoor air was supplied, while at night this warmth was conserved by the heat recovery, being operated again. As a result indoor temperature rises day after day, while the good possibilities for night cooling were neglected as well as the possibilities to conserve cold by operating the HR at day time when outdoor temperatures were above indoor.

3 ENERGETIC PERFORMANCE

Apart from the high extra energy use mentioned before for window opening, to derive differentiated room temperatures in the heating season, other critical issues from HRV are to be mentioned.

A major aspect of HRV of course is how much ventilation energy is recuperated. Figure 5 shows the overall HR efficiency derived from TNO measurements for three systems with a specified unit efficiency of 95%. The real overall efficiency appeared to be a fraction 0.35 to 0.72 of the unit's spec. Roulet [3] reported comparable results ranging from 0.10 to 0.86 times the unit specs. In case of large deviations often clear deficiencies were the cause. But even in apparently well designed and installed situations overall HR efficiency seldom was higher than 70%. Two major reasons for that were insulation losses through the unit ducting to and from outside and buildup of condensate in the small ducts of the HR block, which persisted there for many weeks (Figure 5).

Figure 4 Condensate build-up within the exhaust ducts of the HR block

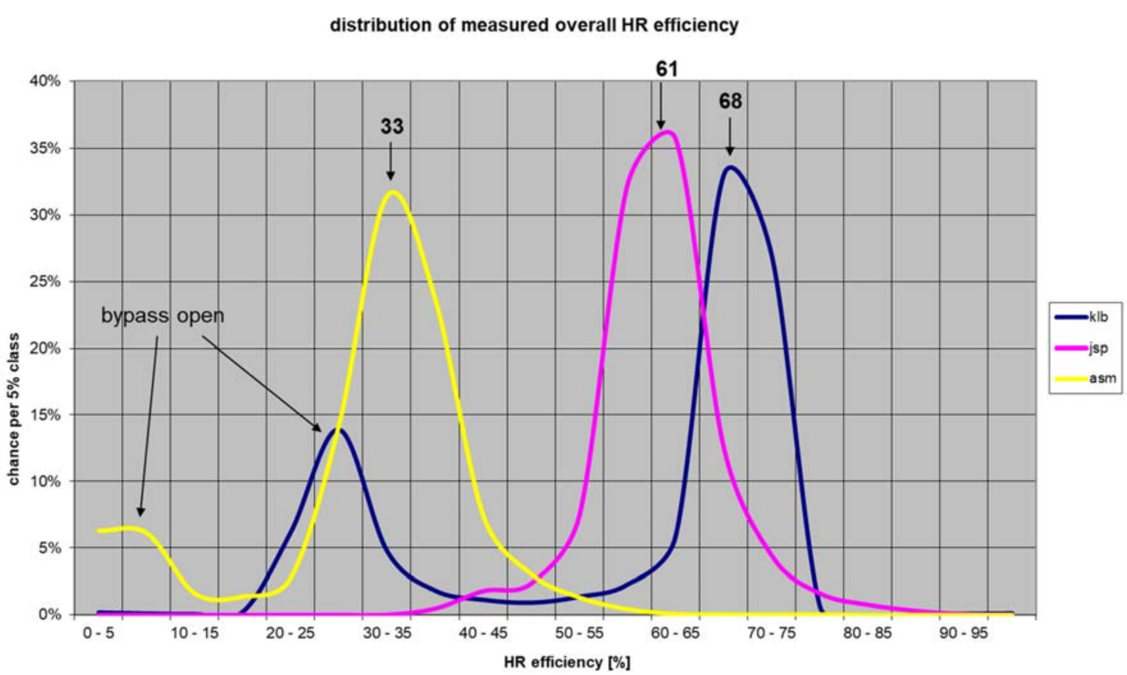

Figure 5 Measured efficiency of heat recovery in 3 cases

The heat recovery efficiency is defined as the temperature raise of supply air compared to the difference between inside and outside temperature. However, in respect to energy use not the temperature efficiency but the enthalpy efficiency would be more suitable. In general exhausted air from HRV systems has an absolute humidity increase of about 1.5 g/kg compared to outside. In a moderate climate, the latent heat portion of this is in the order of half the sensible heat. Hence, what is defined as an overall 70% heat recovery in fact is only about 50% saving on ventilation energy. It is replicated that latent heat isn't produced by the heating system, which allows the use of temperature efficiency as a test standard. However, this is only partly true. What's more, every heat regain should be welcome, whatever the source. Also a HRV enthalpy efficiency would compare better to heat pump efficiency, which does account for both sensible and latent heat. Since a usual heat pump COP of 5 compares to a heat recovery efficiency of 80% a ventilation heat pump has a better performance than the HRV system with its realistic 50% enthalpy efficiency, being sold as COP = 20 because of its 95% unit's temperature efficiency.
Another issue in the comparison to heat pump performance is the electricity use. Where the heat pump is only operated when heat regain is possible and useful, the HR ventilation system is operated continuously, though with different settings, because ventilation is necessary all year. For ventilation of 42 dm^3/s at an average specific fan power of 1 W per dm^3/s the HRV unit would consume 370 kWh/a electricity, compared to 150 kWh for a fan-only system. This corresponds to an extra 2.0 GJ/a primary energy. In the moderate Dutch climate the ventilation energy saving of the HRV system in a well-insulated dwelling is estimated in the order of 6 GJ/a. So the extra energy for electricity use will roughly reduce the total saving on ventilation energy to about 35%. Therefore, a low pressure design is recommended. This would also favor the noise reduction of the system, often addressed as a bottleneck for good usability. This should be combined with a more hybrid multi-mode system, only operating in HR-mode when necessary.

4 CONCLUSIONS AND RECOMMENDATIONS

Improved energy efficiency of dwellings has led to more diversion of heat and cold need between rooms. Central HR ventilation impedes this desired temperature differentiation by redistributing regained heat to rooms with cooling need. This induces extra window airing during the heating season, adversely affecting the HRV efficiency to a high extend.

Energy efficient dwellings show an increasing variation in heat and cold need over the day. This advocates for implementation of a controllable short term heat storage.
A new system set-up is suggested, in which HRV local ventilation heat exchangers per room transfer desired or excess heat to and from this buffer, thus also improving temperature differentiation. Furthermore, the new system needs to operate in season dependant mode, to adapt for ventilative cooling and to restrict electricity use. With this, improvements on condense drain, bypass control and low pressure, low noise design should be addressed.

5 REFERENCES

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